COMPETITOR:
JURNAL PENDIDIKAN KEPELATIHAN OLAHRAGA
e-ISSN: 2657-0734 & p-ISSN: 2085-5389 ‖ Volume 18, Number 1, 2026 ‖ P.1065-1075

VO_2Max West Java Finswimming Athletes Based On Event Category And Performance Achievement

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ABSTRACT

The physical condition of finswimming athletes plays a critical role in determining competitive performance at the XXI National Sports Week (PON) Aceh–North Sumatra 2024. Aerobic capacity, represented by maximal oxygen uptake (VO_2max), reflects the efficiency of the cardiorespiratory system in delivering and utilizing oxygen during high-intensity activity and is widely recognized as a key indicator of endurance performance. This study aimed to examine the relationship between VO_2max, event category (short-, middle-, and long-distance), and performance achievement among West Java provincial training camp finswimming athletes. A quantitative descriptive study with an ex post facto design was employed. Fourteen athletes (7 males and 7 females; aged 16–27 years) were selected using total sampling. VO_2max was assessed using the Multi-Stage Fitness Test (validity = 0.92; reliability = 0.89) at the Sport Science Laboratory, Faculty of Sport and Health Education, Universitas Pendidikan Indonesia. Data were analyzed using Spearman's rho correlation test ($\alpha = 0.05$). The results revealed a significant positive relationship between VO_2max and competitive distance ($r_s = 0.727$; $p = 0.011$) and a very significant relationship between competitive distance and performance achievement ($r_s = 0.784$; $p = 0.004$). However, the relationship between VO_2max and performance achievement was not statistically significant ($r_s = 0.397$; $p = 0.227$). These findings indicate that while aerobic capacity influences event specialization, competitive success is determined by a multifactorial interaction of physiological, technical, and strategic components. The study provides evidence-based guidance for event-specific and holistic training program design in finswimming.

ARTICLE HISTORY
Received: 2026/02/06
Accepted: 2026/02/16
Published: 2026/02/21

KEYWORDS
VO_2max;
Finswimming;
Aerobic Capacity;
Competitive Distance;
Performance Achievement.

AUTHORS' CONTRIBUTION
A. Conception and design of the study;
B. Acquisition of data;
C. Analysis and interpretation of data;
D. Manuscript preparation;
E. Obtaining funding

Cites this Article : Subekti, S.; Sutresna, N.; Santoso, G.A.; Rizkia, F.; Nuraini, S.A. (2026). VO_2Max West Java Finswimming Athletes Based On Event Category And Performance Achievement. **Competitor: Jurnal Pendidikan Kepelatihan Olahraga**. 18 (1), p.1065-1075

INTRODUCTION

The National Sports Week (PON) is the most prestigious multi-sport event in Indonesia, serving as a benchmark for the success of national high-performance sports development. At the 21st PON in Aceh–North Sumatra in 2024, finswimming featured 19

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events, and West Java Province won 4 gold, 8 silver, and 2 bronze medals. This achievement is the result of a long-term development process through a structured and sustainable regional training center (pelatda) program. From the perspective of the national sports system, high-performance development must be implemented systematically, in stages, and based on sports science and technology, as mandated by Law Number 3 of 2005 concerning the National Sports System.

Scientifically, high-performance sports performance is significantly influenced by physical condition, particularly aerobic capacity, which is represented by maximal oxygen uptake (VO_2max). VO_2max is a key indicator of cardiorespiratory fitness, reflecting the ability of the heart, lungs, and peripheral tissues to transport and utilize oxygen during high-intensity activity. Recent studies have shown that aerobic capacity contributes significantly to competitive endurance, recovery speed, and consistent performance in endurance and mixed-energy system sports (Koons et al., 2019; Srivastava et al., 2024). Athletes with a high VO_2max are able to maintain work intensity for longer periods and delay metabolic fatigue (Millah & Priana, 2020).

In the context of finswimming, the physiological demands are complex, involving efficient underwater movement, hydrodynamic control, and the ability to maintain speed across various race distances. Short-distance events require high anaerobic capacity, with aerobic capacity contributing to recovery between stages, while middle- and long-distance events rely more heavily on the aerobic energy system. Therefore, VO_2max is a central component in supporting long-course performance and pacing stability in middle-distance events (Putra, 2021).

Although VO_2max evaluations are routinely conducted in regional training centers, there has been no comprehensive analysis linking differences in VO_2max based on race distance categories (short-, middle-, and long-distance) with actual performance in finswimming athletes at the PON level. This raises a scientific question: are there significant differences in VO_2max across race distance categories, and to what extent do variations in VO_2max contribute to performance? This issue is strategically relevant in efforts to optimize training program design for the next national event.

Research over the past decade has confirmed that VO_2max is a strong predictor of performance in endurance sports. In aquatics, aerobic capacity correlates with metabolic efficiency and fatigue management during competition (Koons et al., 2019; Hartaningrum et al., 2022). Interventions such as High-Intensity Interval Training (HIIT) have been shown to significantly increase VO_2max through central and peripheral adaptations, including increased stroke volume and muscle capillary density (Deliceoğlu et al., 2024).

In swimming and its variations, aerobic capacity influences the ability to maintain optimal speed in the middle lap and determines the quality of sprint finishes (Vasickova, 2017). Biomechanical research by Gautier et al. (2004) demonstrated that race distance influences movement frequency and amplitude, which are closely related to physiological demands and the dominant energy system. Although this study focused on kinematic aspects, its implications indicate differences in physiological requirements based on competition category.

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In the context of Indonesian competitive sports, recent research shows that physical condition, including aerobic endurance, is positively correlated with medal achievements at national events (Santoso et al., 2025; Syahputra et al., 2024). Furthermore, nutritional factors, body composition, and recovery management also influence elite athletes' VO_2max capacity (Koons et al., 2019).

Globally, a sports science approach emphasizes the importance of physiological profiling based on competition categories to develop more precise training periodizations (Musaev, 2021). However, in finswimming, research specifically comparing VO_2max by distance category and linking it to competitive performance remains very limited, especially in the context of Indonesian elite national athletes.

Although the international literature has extensively discussed the relationship between VO_2max and endurance sports performance, several significant research gaps remain.

First, most research focuses on conventional swimming, athletics, or land sports, while finswimming has substantially different biomechanical and hydrodynamic characteristics. Physiological adaptations in finswimming cannot be fully generalized from conventional swimming because monofin/bifin use affects muscle recruitment patterns and propulsion efficiency.

Second, previous research tends to test the effectiveness of training methods on increasing VO_2max without classifying athletes based on race distance categories. Physiologically, sprint and long-distance events have different energy system contributions, potentially resulting in significant differences in VO_2max profiles.

Third, there have been no empirical studies that simultaneously analyze differences in VO_2max across race distance categories and relate them to actual performance within a population of elite athletes training for the PON (National Sports Week). This evidence-based approach is crucial for developing more targeted training models based on the specific needs of the race events.

Fourth, in the context of national sports development, scientific studies based on physiological data from PON athletes are still limited in publication in reputable international journals, so Indonesia's scientific contribution to sports performance analytics still needs to be strengthened.

Thus, this study attempts to fill this gap through a comparative analysis of VO_2max based on race distance categories and its relationship with the achievements of West Java finswimming athletes at the 2024 XXI PON.

This study aims to: (1) Analyze differences in VO_2max values in West Java finswimming athletes based on race categories (short-, middle-, and long-distance); (2) Examine the relationship between VO_2max values and competitive performance at the 21st National Games (PON XXI) in 2024; and (3) Provide a scientific basis for developing training programs based on the physiological characteristics of each race.

The novelty of this study lies in its integrative approach, which combines physiological analysis (VO_2max), race distance classification, and actual performance data in a single empirical analysis model. Unlike previous research that only assessed

increases in VO_2max due to training interventions, this study positions VO_2max as a differential variable between race categories and as a predictor of competitive performance in elite national athletes.

Theoretically, this study enriches the sport physiology literature on finswimming with a distance-based perspective. Practically, the research findings are expected to provide a scientific basis for coaches and regional training center managers in developing more precise training schedules, allowing athlete development for the next National Sports Week (PON) to be more effective, efficient, and evidence-based.

Therefore, this research is not only academically relevant within the context of the SINTA–Scopus journal, but also strategically important in supporting the strengthening of the national sports science-based competitive sports development system.

METHODS

This study applied a quantitative descriptive approach using an ex post facto design, in which variables had naturally occurred and no experimental manipulation was implemented. The ex post facto framework is appropriate for performance analysis in elite sport contexts where intervention is not ethically or practically feasible, and where the objective is to examine naturally existing physiological differences and their association with performance outcomes (Creswell & Creswell, 2018; Mujika, 2017). In sport science research, such designs are widely used to analyze physiological determinants of performance in competitive athletes (Buchheit & Laursen, 2019; McGuigan, 2018).

The population consisted of all West Java provincial training camp (pelatda) finswimming athletes preparing for the XXI National Sports Week (PON) 2024, totaling 14 athletes. Given the limited number of elite athletes within the provincial training system, total sampling was employed, involving all 14 athletes (7 males and 7 females) aged 16–27 years. This approach ensures ecological validity and minimizes sampling bias in elite sport research, where athlete populations are inherently restricted (Hopkins et al., 2019; Halson, 2019). All participants were actively registered in official competition categories (short-, middle-, and long-distance events) under the national finswimming federation.

The primary independent variable was VO_2max, while the dependent variable was performance achievement, operationalized through official competition results at PON XXI 2024. Event category (short-, middle-, long-distance) was treated as a grouping variable. VO_2max is widely recognized as a valid indicator of aerobic capacity and cardiorespiratory fitness, strongly associated with endurance performance, recovery capacity, and competitive consistency (Bassett & Howley, 2015; Koons et al., 2019; Jones et al., 2021). In aquatic and endurance-based sports, higher VO_2max values contribute to improved oxygen delivery, delayed lactate accumulation, and enhanced pacing strategies (Millet et al., 2018; Seiler, 2019).

VO_2max was measured using the Multi-Stage Fitness Test (MSFT), also known as the beep test, which has demonstrated strong validity ($r = 0.92$) and reliability ($r = 0.89$) in

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estimating maximal aerobic capacity (Tomkinson et al., 2018; Mayorga-Vega et al., 2016). The MSFT remains a practical and scientifically supported field-based protocol for assessing aerobic fitness in athletic populations, including adolescent and adult competitors (Lang et al., 2018; Slimani et al., 2018). The test progressively increases running speed in staged intervals until volitional exhaustion, enabling indirect estimation of VO_2max through standardized predictive equations.

Testing procedures were conducted at the Sport Science Laboratory, Faculty of Sport and Health Education (FPOK), Universitas Pendidikan Indonesia (UPI) under the supervision of certified sport scientists and exercise physiologists to ensure procedural standardization and measurement accuracy. Prior to testing, athletes underwent a standardized warm-up and health screening protocol in accordance with current exercise testing guidelines (American College of Sports Medicine [ACSM], 2022). Environmental conditions, hydration status, and recovery intervals were controlled to reduce confounding variables known to influence aerobic performance outcomes (Halson, 2019; Saw et al., 2016).

Data analysis included descriptive statistics (mean, standard deviation, minimum–maximum values) to profile VO_2max across event categories. Inferential analysis was performed to examine differences in VO_2max among short-, middle-, and long-distance athletes and to determine its relationship with performance achievement. Normality was assessed using the Shapiro–Wilk test, followed by appropriate parametric or non-parametric procedures (Field, 2018). Effect sizes were calculated to determine the practical significance of findings, as recommended in contemporary sport performance research (Lakens, 2017; Hopkins et al., 2019).

This methodological approach allows for evidence-based profiling of aerobic capacity in elite finswimming athletes and provides a scientific foundation for event-specific conditioning strategies.

RESULTS AND DISCUSSION

Result

This study analyzed the relationship between aerobic capacity (VO_2max), competition event category, and performance achievement among West Java provincial training camp (pelatda) finswimming athletes who competed at the XXI National Sports Week (PON) 2024. Of the 14 registered athletes, 11 met the inclusion criteria and completed the full physiological testing protocol.

Descriptive Analysis of VO_2max

VO_2max values ranged from 35.5 to 53.8 $ml \cdot kg^{-1} \cdot min^{-1}$, with a mean of 44.71 ± 5.62 $ml \cdot kg^{-1} \cdot min^{-1}$. These values fall within the moderate-to-high aerobic fitness category for competitive aquatic athletes (Jones et al., 2021; ACSM, 2022). Previous research indicates that elite endurance athletes typically demonstrate VO_2max levels above 50 $ml \cdot kg^{-1} \cdot min^{-1}$, whereas mixed-distance competitors may present moderate ranges depending on event specialization (Millet et al., 2018; Seiler, 2019).

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Table 1.
Descriptive Statistics of VO_2max (n = 11)

Variable	Min	Max	Mean	SD
VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	35.5	53.8	44.71	5.62

When grouped by competition distance, long-distance athletes demonstrated the highest mean VO_2max values, consistent with the dominance of oxidative metabolism in prolonged underwater propulsion (Buchheit & Laursen, 2019; Sandbakk et al., 2021).

Table 2.
VO_2max Based on Event Category

Event Category	n	Mean VO_2max	SD
Short Distance	4	39.88	3.12
Middle Distance	4	45.95	2.87
Long Distance	3	50.23	2.94

The progressive increase in VO_2max from short- to long-distance categories aligns with physiological profiling literature emphasizing higher aerobic requirements in endurance-dominant events (Stöggl & Sperlich, 2015; McGuigan, 2018). Similar patterns have been reported in swimming and other aquatic sports, where distance specialization is strongly associated with aerobic capacity differentiation (Pyne et al., 2019; Rodríguez & Mader, 2020).

Spearman's rho correlation analysis revealed three principal findings.

VO_2max and Competitive Distance

A significant positive correlation was found between VO_2max and competition distance (r_s = 0.727; p = 0.011). This indicates that athletes with higher aerobic capacity tended to compete in middle- and long-distance events. The strength of this correlation falls within the "strong" category (Hopkins et al., 2019).

This finding is consistent with contemporary sport physiology research demonstrating that aerobic power is a key determinant in endurance-based event allocation (Millet et al., 2018; Jones et al., 2021). In finswimming, prolonged undulatory propulsion increases oxygen demand and mitochondrial energy turnover, explaining the higher VO_2max observed among long-distance specialists (Rodríguez & Mader, 2020).

Competitive Distance and Performance Achievement

A very significant correlation emerged between competition distance and performance achievement (r_s = 0.784; p = 0.004). Athletes competing in longer-distance events showed a greater likelihood of medal attainment.

This result supports endurance-performance models suggesting that aerobic dominance enhances pacing control, fatigue resistance, and performance stability during championship events (Sandbakk et al., 2021; Seiler, 2019). Long-distance athletes may benefit from greater physiological consistency under competitive stress, which increases medal probability in structured multi-lap events (Buchheit & Laursen, 2019).

VO_2max and Performance Achievement

The relationship between VO_2max and performance achievement was not statistically significant (r_s = 0.397; p = 0.227), although a positive trend was observed.

While aerobic capacity contributes to physiological readiness, performance outcomes are multifactorial and influenced by biomechanical efficiency, tactical

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strategy, neuromuscular power, psychological resilience, and hydrodynamic optimization (McGuigan, 2018; Halson, 2019; Saw et al., 2016). Previous elite sport studies indicate that beyond a certain threshold, incremental VO_2max differences may not directly translate into medal outcomes, particularly in sprint-oriented or mixed-energy events (Jones et al., 2021; Stöggl & Sperlich, 2015).

Table 3.
Spearman's Rho Correlation Results

Variables Compared	r_s	p-value	Interpretation
VO_2max – Event Category	0.727	0.011	Significant
Event Category – Achievement	0.784	0.004	Very Significant
VO_2max – Achievement	0.397	0.227	Not Significant

The findings suggest that event category serves as a mediating factor between aerobic capacity and medal achievement. While VO_2max significantly differentiates athletes by competition distance, its direct association with performance achievement appears moderated by other physiological and technical determinants.

Contemporary performance analytics emphasize integrated profiling rather than reliance on single physiological indicators (Hopkins et al., 2019; Sandbakk et al., 2021). Therefore, although VO_2max remains a critical foundation of endurance capacity, medal success in finswimming is likely determined by the interaction of aerobic fitness, biomechanical efficiency, race strategy, and psychological readiness.

Overall, this study provides empirical evidence that aerobic capacity differentiates event specialization among West Java finswimming athletes, and that longer-distance specialization is associated with higher medal probability at PON XXI 2024.

Spearman's Rho Correlation Analysis

Spearman's rho correlation analysis was conducted to examine the relationship between VO_2max, race distance category, and performance in finswimming athletes from the West Java Regional Training Center (n = 11). This non-parametric test was used because the data distribution was not completely normal and the sample size was relatively small, in accordance with methodological recommendations in sports science research (Field, 2018; Hopkins et al., 2019).

Discussion

The results of this study indicate a significant positive relationship between VO_2max and race distance category in West Javanese finswimming athletes. This finding aligns with modern exercise physiology principles, which emphasize that the longer an event lasts, the greater the aerobic energy system's contribution to maintaining speed and stable performance (Millet et al., 2018; Seiler, 2019). In middle- and long-distance events, oxidative metabolism becomes dominant due to the need for sustained and efficient ATP production. Athletes with a high VO_2max have better oxygen transport and utilization capacity, enabling them to maintain submaximal speeds for longer with more controlled lactate accumulation (Jones et al., 2021; Sandbakk et al., 2021).

In the context of finswimming, the hydrodynamic characteristics and use of monofins demand consistent neuromuscular coordination and propulsive efficiency

throughout the course. Recent studies in aquatics have shown that aerobic capacity is strongly correlated with pacing and fatigue management in events lasting >2 minutes (Pyne et al., 2019; Rodríguez & Mader, 2020). These research findings support the argument that athletes with higher VO_2max tend to specialize in middle- and long-distance events, as the metabolic demands of these events rely more on oxidative capacity than on the anaerobic alactacid system.

Conversely, shorter-distance events in finswimming place greater emphasis on the contribution of the phosphagen system (ATP-PCr) and fast glycolysis, which orientate toward explosive power and initial speed (Buchheit & Laursen, 2019; McGuigan, 2018). Therefore, a very high VO_2max is not a primary prerequisite for success in sprint events. Sports performance literature confirms that events lasting <60 seconds are significantly influenced by strength, rate of force development, and neuromuscular efficiency (Cormie et al., 2016; Suchomel et al., 2018). Therefore, the results of this study support a physiological profile-based specialization approach, as recommended in modern long-term athlete development models (Lloyd et al., 2016; Safei et al., 2021).

However, the relationship between VO_2max and performance did not show statistical significance, despite a positive trend. This indicates that competitive finswimming performance is multifactorial. Recent literature emphasizes that at the elite athlete level, competitive success is not determined by a single fitness component, but rather by the integration of physiological capacity, biomechanical technique, tactical strategy, and psychological preparedness (Halson, 2019; Saw et al., 2016; Jones et al., 2021). In aquatic sports, factors such as streamline efficiency, amplitude–frequency kicking ratio, underwater starts and turns, and the ability to minimize hydrodynamic drag have a major contribution to race results (Pyne et al., 2019; Rodríguez & Mader, 2020).

In this study, the possibility of a "ceiling effect" needs to be considered. National Games athletes generally have relatively homogeneous VO_2max levels, ranging from good to excellent. Under these conditions, small variations in VO_2max are no longer a major differentiator in determining medal outcomes (Hopkins et al., 2019; Sandbakk et al., 2021). Similar findings have been reported in elite endurance studies, where, after passing a certain aerobic capacity threshold, movement efficiency and energy economy become stronger determinants than increases in VO_2max alone (Jones et al., 2021; Seiler, 2019).

Furthermore, the relatively small sample size (n = 11) potentially reduces statistical power in detecting stronger relationships. In elite performance research, population limitations are often an unavoidable methodological constraint (Hopkins et al., 2019). The presence of athletes who did not perform optimally or experienced disqualifications can also affect the distribution of performance data, reducing the sensitivity of correlation analyses.

The highly significant relationship between distance category and performance is a strategic finding. Athletes competing in longer distance events demonstrate a greater probability of winning medals. This can be explained by the characteristics of endurance events, which allow for more controlled pacing and more distributed technical errors throughout the race (Millet et al., 2018). Sprint events tend to have a very small margin of error; even a slight start or coordination error can have a significant impact on the final result (Cormie et al., 2016).

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From a coaching perspective, these results have clear practical implications. Early identification of event specialization requires considering the athlete's physiological profile, particularly aerobic capacity. Athletes with a high VO_2max should be directed toward middle- and long-distance events with an emphasis on endurance training, moderate-to-high intensity intervals, and developing movement economy (Seiler, 2019; Buchheit & Laursen, 2019). Conversely, athletes with dominant power characteristics can focus on sprint events with a training approach based on explosive strength and reaction speed (Suchomel et al., 2018).

However, the training approach should not be reductionist. The development program must be holistic, integrating technical, biomechanical, nutritional, and sports psychology components. The literature shows that recovery management, sleep quality, and hydration status influence competitive performance in high-intensity sports (Halson, 2019; Saw et al., 2016). Furthermore, strengthening mental aspects such as competitive anxiety regulation and attentional focus also contribute significantly to performance consistency (McGuigan, 2018).

Further research is recommended to involve a larger sample size and include other physiological and biomechanical variables, such as leg muscle strength, body composition, monofin propulsion efficiency, and psychological variables. Integrating multivariate analysis can provide a more comprehensive picture of the determinants of finswimming performance at the elite level (Santoso, 2024; Sandbakk et al., 2021).

Overall, this research confirms that VO_2max plays a crucial role in determining event specialization, but does not directly guarantee achievement. Competitive success is the result of a synergy between physiological capacity, technical efficiency, and psychological preparedness. These findings reinforce the urgency of an evidence-based sports science approach in the athlete development system for national and international events.

CONCLUSION

This study demonstrated a significant positive relationship between VO_2max and competitive distance (r_s = 0.727; p = 0.011), as well as a very significant association between competitive distance and performance achievement (r_s = 0.784; p = 0.004). These findings confirm fundamental principles of exercise physiology indicating that longer-duration events rely predominantly on aerobic metabolism, thereby requiring higher maximal oxygen uptake capacity to sustain optimal speed and delay fatigue. Athletes with superior aerobic profiles were more likely to specialize in middle- and long-distance swimming events and showed greater competitive performance potential within those categories.

However, the relationship between VO_2max and performance achievement did not reach statistical significance (r_s = 0.397; p = 0.227), suggesting that competitive success in finswimming cannot be explained by aerobic capacity alone. Performance outcomes reflect a multifactorial interaction among physiological capacity, biomechanical efficiency, technical skill execution, tactical strategy, and psychological readiness.

Overall, these findings provide empirical support for implementing event-specific athlete profiling and training prescription. Coaches are encouraged to adopt a holistic, evidence-based approach that integrates aerobic development with technical refinement, neuromuscular conditioning, and mental preparation to optimize competitive achievement.

ACKNOWLEDGMENTS

The author would like to express sincere gratitude to the Sports Laboratory of the Faculty of Sport and Health Education (FPOK) for providing comprehensive facilities, technical resources, and professional supervision throughout the implementation of this research. The availability of standardized testing equipment, controlled laboratory conditions, and expert guidance from sport science personnel significantly contributed to the accuracy, reliability, and scientific rigor of the VO_2max assessments conducted in this study.

Appreciation is also extended to the West Java provincial training camp (pelatda) finswimming athletes and coaching staff for their cooperation, discipline, and commitment during the data collection process. Their willingness to participate and adhere to testing protocols ensured the integrity of the research procedures.

Furthermore, the author acknowledges the valuable academic support and constructive discussions from colleagues and sport science practitioners who provided insights related to physiological profiling and performance analysis. Their input enriched the interpretation of findings and strengthened the empirical foundation of this study.

This research would not have been possible without the collaborative synergy between academic institutions and sport performance stakeholders committed to advancing evidence-based athlete development.

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